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NONMAGNETIC, EXPLOSIVE ACTUATED INDEXING DEVICE

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ABSTRACT

A nonmagnetic, explosive-actuated indexing device was developed for a magnetometer experiment flown on the Pioneer VI and VII spacecrafts. Conventional indexing devices were not suitable for use in instruments designed to measure low-intensity magnetic fields. This device features an arrangement by which new explosive piston actuators are cycled into position to provide eleven independent operations. The pistons actuate a bistable escapement which permits precise 180-degree rotation of the magnetometer sensor. Although the device was designed for a specific purpose, it is basically a nonmagnetic stepping motor. It can be modified for other stepping increments, and more operations can be provided.

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INTRODUCTION

The development of a nonmagnetic indexing device was required so that the magnetometer experiment aboard Pioneer spacecrafts could be calibrated during flight. The magnetometers for these missions were designed to measure spatial magnetic fields between the orbits of Venus and Mars. The intensity of the magnetic field in this region is below 10 gammas (1 gamma = 10^{-5} oersted); thus, it was essential to minimize the permanent field of the instrument and measure the drift in the magnetometer.

Permanent fields are minimized by using only nonmagnetic materials. A calibration technique in which the magnetometer sensor is rotated 180 degrees to take two measurements in exactly opposite directions determines the drift in the sensor. A novel feature of this device is the way in which repeated operations are obtained with explosive piston actuators. Normally such devices are used for one-shot operations because, by their very nature, they can be detonated only once and are not retractable. However, this design overcomes these deficiencies with a sequential firing arrangement and automatic replacement of spent actuators. This report describes the mechanical and electrical functions of the design which evolved, and the unique problems encountered. It concludes with an evaluation of the objectives achieved and suggests other applications for this device.

OBJECTIVE

The prime objective of this program was to develop a nonmagnetic device capable of repeatedly indexing the magnetometer sensor precisely 180 degrees on command. The requirements essential to achieving this were defined as follows.

1. The permanent magnetic field of the mechanism must be less than 0.25 gammas at 0.5 inch.
2. Rotation must be 180 degrees ±15 minutes within 15 seconds after receipt of command.
3. The device must have a minimum capability of 10 cycles.
4. The power required must be less than 1 watt.
5. Maximum allowable weight, including magnetometer, is 0.75 lb.
6. The device must fail-safe; i.e., the magnetometer must not stop in any position other than the two specific positions.

DESIGN

In selecting a design approach, conventional indexing devices such as electrical stepping motors and solenoids were eliminated because of their inherent magnetic fields. Therefore, effort was concentrated on adapting spring-powered devices. The spring-powered, explosive-actuated, bistable escapement concept evolved and was adopted for the following reasons.

1. The device can be made entirely of nonmagnetic materials.
2. It provides positive indexing in response to remote commands.
3. It is fail-safe in that nothing can stop the shaft except the designed stops.
4. It requires a minimum amount of electrical power.

MECHANICAL OPERATION

A monoaxial fluxgate magnetometer indexing device of this design is shown in Figure 1. Figure 2 is an exploded view depicting the principle parts. The mechanical operation is as follows.

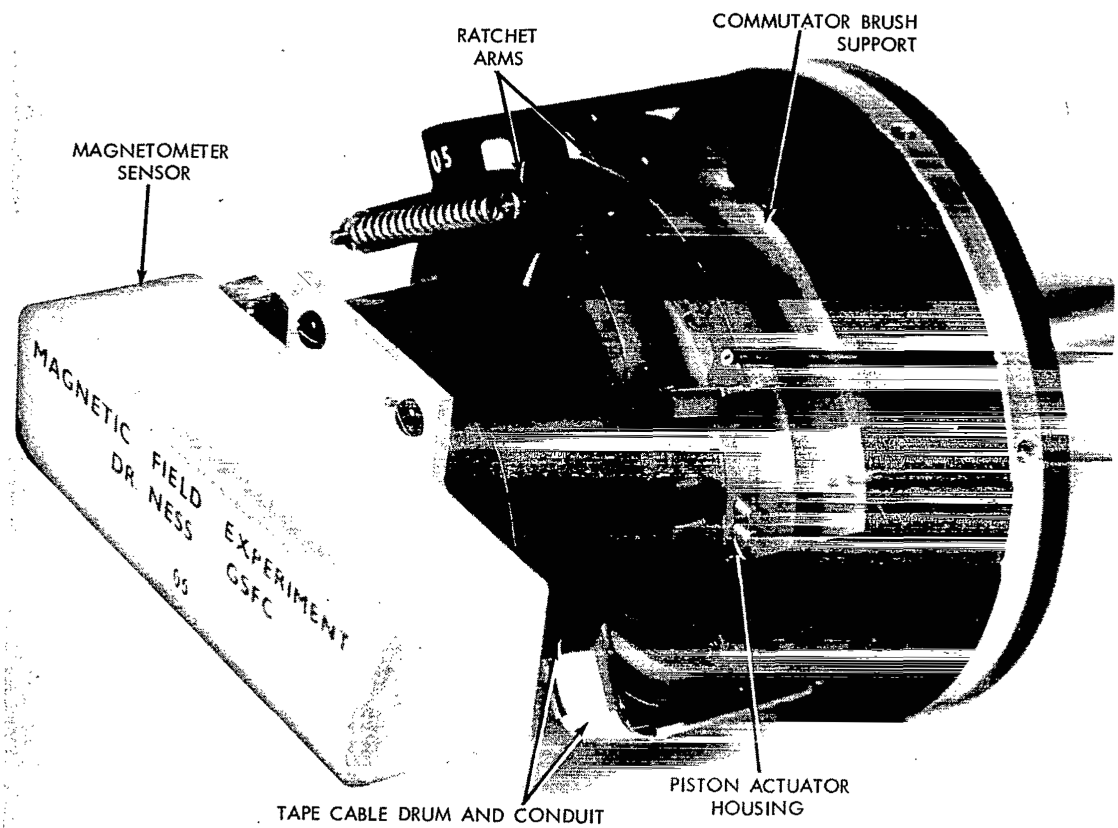

Figure 1—Fluxgate magnetometer indexing device.

The magnetometer sensor and a coil of tape cable are positioned upon a rotatable shaft. Attached to this shaft is one end of the power spring; the opposite end of this spring is attached to the spring housing, which in turn fastens to the actuator housing. These housings are concentric to the shaft so that when the spring is wound, a torque tends to rotate the shaft and housings in opposite directions.

The escapement which controls this rotation consists of a ratchet, which is attached to the shaft, and a mating part designated as the sensor ratchet arm. The 180-degree indexing of the magnetometer sensor is a function of the shape and pivoting of this arm. The bistable feature is obtained by an off-center spring fastened from the arm to the main structure, across the pivot point.

Figure 3—Ratchet engagement.

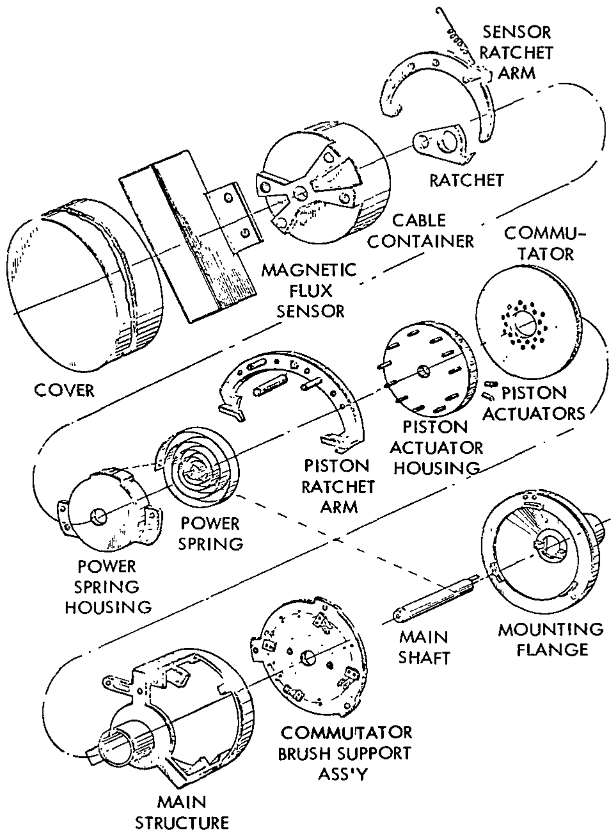

Figure 2—Exploded view of indexing device.

A second arm is attached to the previously mentioned arm and pivots with it. This arm has two piston impact surfaces positioned 180 degrees from each other. The arm engages the piston actuator housing and alternately mates the opposite impact surfaces with a pair of explosive piston actuators. Eleven pairs of piston actuators are housed about the periphery of this disk. Two actuators are used for redundancy. Figure 3 shows the piston actuators that have been fired and those that will move into position. The housing is indexed by means of protruding pins that engage the ratchet arm. The spring housing also engages four of these pins to transmit the drive torque.

The force of detonation extends a piston 1/8 inch. The piston is directed against one of the piston impact surfaces of the second ratchet arm. The ratchet arm pivots outwardly and carries the first ratchet arm along with it. The ratchet, along with main shaft and magnetometer sensor, disengages the first ratchet arm and rotates 180 degrees. It then engages the opposite side of the ratchet arm, coming to rest in its other position.

Simultaneously, the second ratchet arm permits the piston actuator housing to rotate 15 degrees. In this manner, another pair of piston actuators are positioned under the opposite piston surface and are available for another detonation command. Figure 4 shows the ratchet arms, and illustrates the piston impact surfaces, the stops for the 180-degree ratchet, and the stops for the piston actuator housing. Figure 5 illustrates the piston actuator housing and the 11 ratchet pins that engage the second ratchet arm. A printed circuit commutator is attached to the other side, and the piston actuator leads are soldered to terminals on the commutator. This assembly rotates on the main shaft, but in the direction opposite that of the magnetometer.

In Figure 6 the ratchet and sping are shown attached to the main shaft. The hole at the far end is the magnetometer pinhole, and the protruding pin at the near end operates a pair of switches that indicate the magnetometer position.

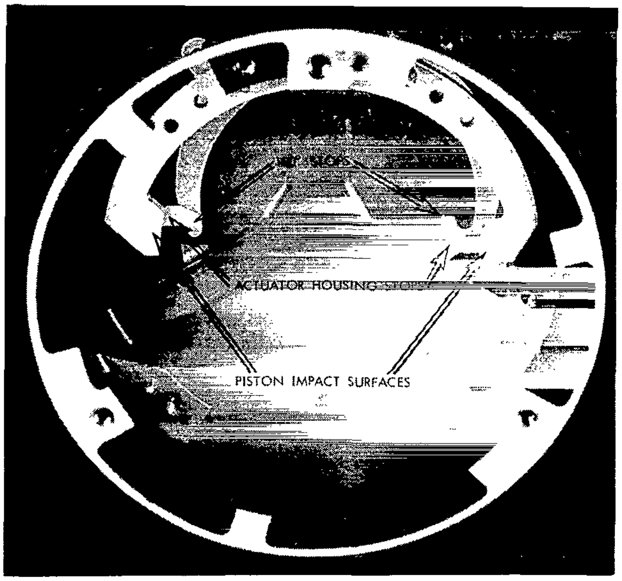

Figure 4—Ratchet arms.

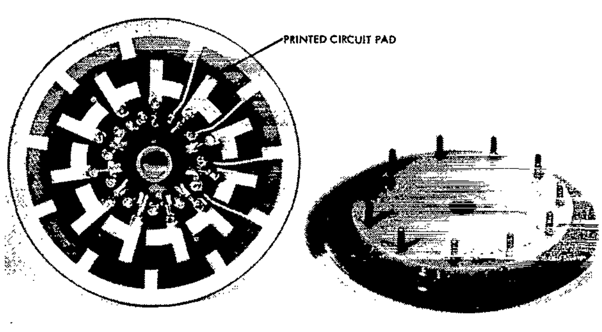

Figure 5—Commutator and piston actuator housing.

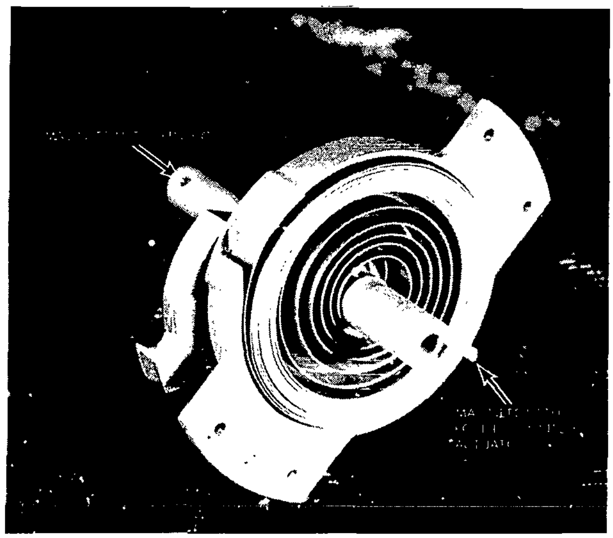

Figure 6—Main shaft with ratchet arm and spring.

LUBRICATION

To compensate for the friction and cold-weld problems normally associated with the vacuum of the space environment, mating moving parts were especially treated. Shafts were made of aluminum, hardcoated, then precision-ground to provide a hard oxide surface. Molybdenum disulfide (MoS_2) was then bonded to this surface. The main shaft is supported in acetal bushings.

The piston actuator housing, which rotates on the main shaft, is also made of acetal. An aluminum thrust washer, treated with the same process as the shafts, supports the rotating parts under a constant centrifugal acceleration of 12g imposed by the spinning spacecraft.

ELECTRICAL FUNCTIONS

The following sequence of events occurs in the ordnance circuit on receipt of an indexing command. A circuit in the magnetometer electronics charges a 100 -μf capacitor to 12 volts in 10 seconds. Then the capacitor is electronically switched to the commutator brushes, which direct the power to the proper piston actuators. The discharge burns the bridge wires, detonating the piston actuators. A 27-ohm resistor in the magnetometer electronics effectively shunts the firing terminals of the piston actuators. This eliminates the possibility of a charge remaining in the circuit which could fire the next set of actuators when they move into position.

The commutator routes the firing impulses, protects the reserve pistons, and completes the circuits that indicate which position of the actuator housing is ready to fire. The commutator consists of two parts. The first is the brush support assembly (Figure 7) that attaches to the main structure. Sixteen pairs of brushes are attached to this support. They are used in pairs for redundancy and, henceforth, will be considered a single brush. The second part is a printed circuit disc which, as previously mentioned, is fixed to and rotates with the piston actuator housing. Pairs of piston actuators are wired in parallel to terminals on this portion of the commutator. One terminal of each pair of piston actuators is electrically connected to ground. The other common terminal of each pair connects to an individual printed circuit pad. The outer track is a continuous conductor. Two diametrically opposed brushes contact this conductor, completing a tie with the ground circuit of the magnetometer electronics.

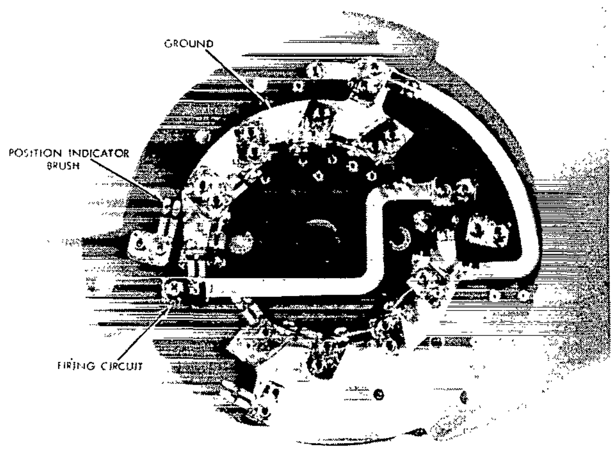

Figure 7—Commutator brush support.

The adjacent inner track has conductive segments extending inward from the ground track at intervals corresponding to alternate steps of the commutator rotation. Again, two diametrically opposed brushes alternately contact the conductive segments, completing circuits which indicate the actuator firing position.

The two innermost tracks consist of conductive segments which are common to each other. These constitute the individual pads previously mentioned to which the actuators are attached. The conductive segments on the innermost track are two intervals long, while the other track has segments only one interval long. Two diametrically opposed brushes wipe the single interval track and connect the actuators to the firing circuit. Although the brushes are electrically common to each other, it is the position of the piston actuator housing that determines which pistons are fired.

Finally, the innermost track provides protection against the accidental firing of reserve actuators with a shorting circuit. Ten brushes wipe the inside track. These brushes are attached to a common printed circuit which is electrical ground and common with the two outside grounding brushes. The printed circuitry of the brush support board connects the brushes with terminals which are wired to the interface connector (Figure 8). Also, located on the brush support board is a miniature electrical connector. During shipment and some tests, a plug is inserted in this connector that directly shorts the piston actuators in the firing position to prevent accidental operation.

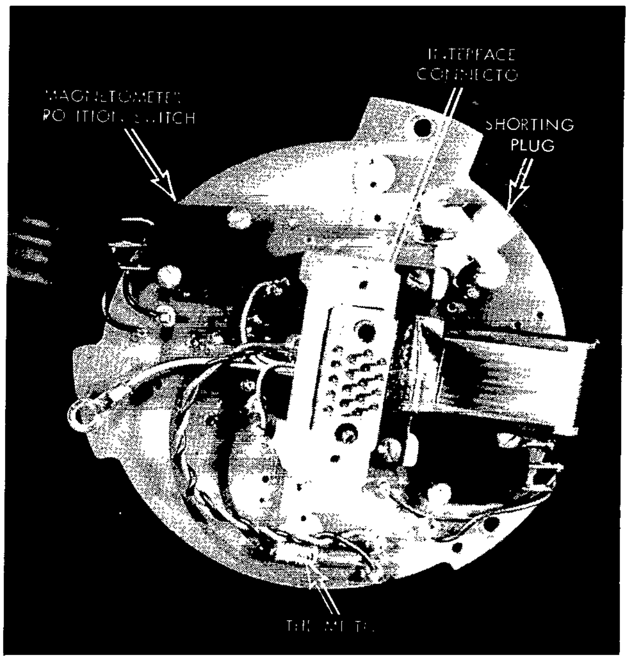

Figure 8—Connector side of commutator brush support.

The nonmagnetic snap switches, also located on the brush support board, are part of the magnetometer sensor position-indicating circuit. The switches are actuated by the pin which is eccentrically located on the end of the main shaft opposite the sensor. The switches close circuits in the experiment electronics which send this information through the spacecraft telemetry system to the ground receiving station.

MAGNETOMETER SENSOR CIRCUIT

Because of the weak signals obtained directly from the fluxgate magnetometer, a commutator could not be used for the seven electrical connections to it. Conventional wiring would be too cumbersome, since the magnetometer makes 5-1/2 rotations. A solution was found in tape cable. The tape cable utilized has five layers for a total thickness of 0.007 inch. It is copper-bonded mylar arranged in a configuration that provides a seven-conductor shielded cable. One end of this cable terminates in a printed-circuit connector that plugs into the magnetometer sensor. To permit

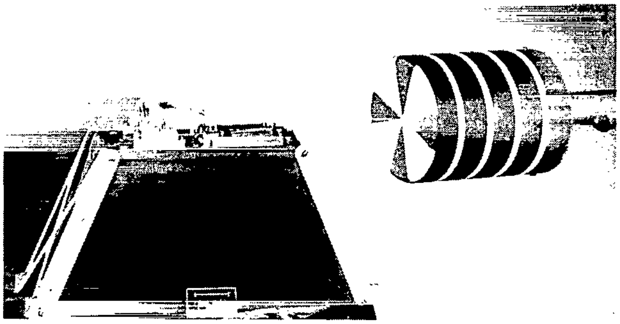

Figure 9—Pioneer magnetometer experiment—sensor with thermal cover and electronics.

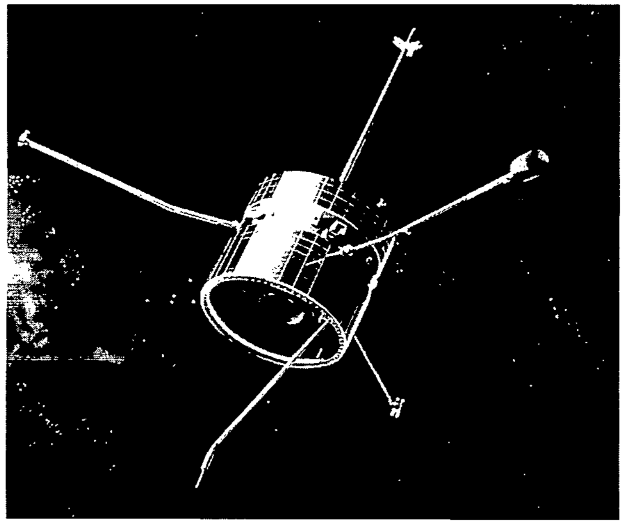

Figure 10—Pioneer VI and VII spacecraft with magnetometer sensor on a boom.

the desired rotation, this cable is coiled in a housing directly beneath the sensor. It then goes through a U-shaped conduit, out and over the indexing mechanism, terminating in the interface connector.

Figure 9 shows the device mounted on the end of the boom with the fiberglass thermal cover for the inbound mission. Also included is the magnetometer electronics package that is mounted inside the spacecraft. Figure 10 is an illustration of the Pioneer spacecraft showing the indexing device on the end of the boom.

MATERIALS

The prime consideration in the selection of materials for this device was magnetic permeability. Next came weight, and then strength. All springs were made from elgiloy. Magnesium was used for the tape cable and power spring housings. The main structure was originally fabricated from magnesium, then later from aluminum to raise the resonant frequency of the mechanism above that of the spacecraft. The shafts and ratchet arms were of hardcoated aluminum. The ratchet was of titanium to better withstand the impact and wear from the ratchet arms.

The cover for the magnetometer sensor and the piston actuator housing were made from acetal. The commutator was made from fiberglass printed circuit boards, and the thermal cover of molded fiberglass. The commutator brushes were beryllium copper.

DEVELOPMENT PROBLEMS

The only major problem was encountered when the prototype instrument was first actuated on the spacecraft. The magnetometer rotated 360 degrees instead of 180 degrees. This mode of failure only occurred when the device was attached to the spacecraft boom. High-speed movies clearly illustrated the dynamic coupling between the ratchet arms and twisting of the boom, when the rotating ratchet hit the stop. This motion caused the ratchet arms to return to their original position, and the magnetometer would continue rotating through 360 degrees and return to its initial position of 0 degrees. However, in this position the resulting forces from the impact held the ratchet arms in position. The situation was corrected by increasing the off-center spring tension and by adding an additional spring to hold the ratchet arms in the 180-degree position.

Two interesting problems occurred with materials selected for this device. In both cases materials which are normally nonmagnetic were found to be magnetic. In one instance, the elgiloy power spring had oxidized because of a heat treatment, and the oxide coating was slightly magnetic. In the other, the position-indicating snap switch cases and the seals through which the piston-actuator electrical leads passed were made of a glass-filled plastic resin that was found to be magnetic. Investigation revealed this to be a function of the fiber length; lengthening the glass fibers corrected the condition.

ALTERNATE CONFIGURATIONS

A number of different ways exist to obtain the same mechanical output. For example, the dual ratchet arms could be replaced with a single ratchet arm and gear-train coupling between the actuator housing and the main shaft. Such a device has been built utilizing a planetary gear system. The bistable escapement was selected for this application principally because it provides an additional fail-safe feature. This feature assures proper sensor alignment, in that it can latch only in the 0- to 180-degrees positions.

SENSOR ORIENTATION

For the experiment to obtain both the value and direction of the spatial magnetic field, measurements must be made in three orthogonal directions. This is done on a spinning satellite with a single sensor in the following way. The sensor is mounted so that its measurement axis makes an angle of 54° 45' with the spacecraft spin axis. Three measurements are made during each revolution of the spacecraft at precisely 120° apart. The experiment electronics, with an input from a sun sensor, determine the exact spin rate and the time of each measurement. Figure 11 illustrates how the 54° 45' is derived.

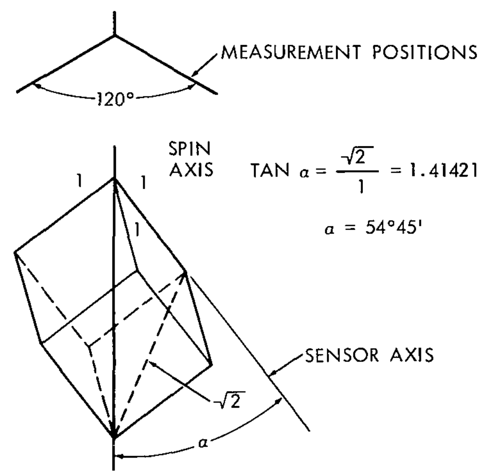

Figure 11—Schematic for three orthogonal measurements with one sensor on a spinning spacecraft.

PERFORMANCE

The program described in this report substantiates the feasibility of the selected approach. There were relatively few problems encountered and these were satisfactorily resolved. The indexing is positive; the sensor rotates 180 degrees, ±10 minutes, within 12 seconds of receipt of command. The permanent magnetic field of the model is less than the 0.25 gamma objective. The power required is much less than 1 watt, and the weight is 0.70 pound.

This device was first flown on Pioneer VI, which was launched December 16, 1965. It was first actuated in space on December 23, 1965 and has been actuated eight more times since then. The latest actuation was December 16, 1966, when the spacecraft was 80 million miles from the earth. A second unit was flown on Pioneer VII August 17, 1966, and, as of this writing, has been operated four times. Other applications for this device include an X-ray camera for sounding rocket experiments. In this type of camera, each frame has its own filter, and these frames must be positioned accurately for calibration. This device could also be used as a nonmagnetic command programmer in which each step of the commutator initiates a different event.

Scientific results from this experiment have been reported by N. F. Ness et al., (1966), N. F. Ness (1966), and K. G. McCracken and N. F. Ness (1966).

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National Aeronautics and Space Administration
Greenbelt, Maryland, November 21, 1966
811-12-00-01-51

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